

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
15 May 2003 (15.05.2003)

PCT

(10) International Publication Number
WO 03/041283 A2

(51) International Patent Classification⁷: **H04B**
(21) International Application Number: PCT/US02/35841
(22) International Filing Date:
7 November 2002 (07.11.2002)
(25) Filing Language: English
(26) Publication Language: English
(30) Priority Data:
60/337,028 7 November 2001 (07.11.2001) US
(71) Applicant (*for all designated States except US*): **EFFICIENT SPECTRUM, INC.** [US/US]; 901 North Pollard Street, Suite 411, Arlington, VA 22203 (US).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **ZANCEWICZ, Gregory, J.** [US/US]; 3540 Fieldstone Crs., Apharetta, GA (US). **KENEMER, Keith** [US/US]; 1050 Lenox Park Blvd, Atlanta, GA 30319 (US).
(74) Agent: **SOFER, Joseph**; Sofer & Haroun, L.L.P., Suite 910, 317 Madison Avenue, New York, NY 10017 (US).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD AND APPARATUS FOR COMBINED DIGITAL ADAPTIVE BEAMFORMING AND DEMODULATION IN A SPACE DIVISION MULTI-ACCESS/CODE DIVISION MULTI-ACCESS (SDMA/CDMA) RECEIVER

(57) Abstract: The present invention increases the capacity of wireless systems employing Space Division Multiple Access (SDMA) receivers and other methods of shaping antenna beams by combining the processing for modulation/demodulation and digital adaptive beamforming in a single functional block. In the preferred embodiment, the present invention combines processing for such beamforming with processing for Code Division Multiple Access (CDMA) modulation/demodulation or Orthogonal Frequency Division Multiplexing (OFDM) modulation/demodulation. In the preferred embodiment, the present invention matches the polarization of an antenna array with that of a mobile-of-interest by optimizing the polarization separately after optimizing antenna array weights. As a result, the present invention can significantly improve the overall post-detection carrier-to-noise-and-interference-ratio (CINR), and thus increase capacity of the wireless link, for example, the CDMA or OFDM link.



WO 03/041283 A2

TITLE

METHOD AND APPARATUS FOR COMBINED DIGITAL
ADAPTIVE BEAMFORMING AND DEMODULATION IN A SPACE
DIVISION MULTI-ACCESS/CODE DIVISION MULTI-ACCESS
5 (SDMA/CDMA) RECEIVER

RELATED APPLICATIONS

10 The present application relates back to a provisional application, Serial
Number 60/337,028, filed November 7, 2001, entitled "Method and Apparatus
for Combined Digital Adaptive Beamforming and Demodulation in a Space
Division Multiaccess/Code Division Multiaccess (SDMA/CDMA) Receiver,"
and incorporated herein by reference.

15 In addition, the present application relates back to a utility application,
filed August 1, 2000, entitled "Application for United States Letters Patent for
Genetic Adaptive Antenna Array Processor," which in turn relates back to a
provisional application, Serial Number 60/147,098, filed August 4, 1999, entitled
"Genetic Adaptive Antenna Array Processor," and incorporated herein by
20 reference.

FIELD OF THE INVENTION

The present invention relates to wireless communications systems. More
25 particularly, the present invention relates to a novel and improved system,
method, and apparatus to increase the capacity of transmitters/receivers that
employ SDMA techniques and other methods of shaping antenna beams.

BACKGROUND

SDMA or “smart antenna” techniques belong to the overall class of
5 adaptive antenna array processing techniques. All adaptive antenna array
techniques generally have the following features in common:

1. An array of individual antenna elements is available to some receiver and/or
transmitter.
2. The system can independently adjust the amplitude and phase of the signal
10 received from and/or transmitted by each element.
3. An optimization process adjusts the amplitudes and phases of individual
elements to optimize some objective function measured at the output of the
receiver.

RF adaptive beamforming (RFAB) systems provide multiple fixed
15 amplitude and phase weights at the antenna terminals, usually in the form of
some switched multiport matrix. Digital adaptive beamforming (DABF) systems
perform amplitude and phase weighting at baseband, so that each user essentially
has its own uplink and/or downlink beam.

DABF systems can be categorized in terms of: (1) the objective function
20 employed to perform beamsteering; and (2) the optimization technique employed
to optimize the objective function. A class of DABF systems that has gained
widespread acceptance in the wireless industry is the class that relies on angle-of-
arrival (AOA) estimates for individual signals and in turn uses this information to
synthesize appropriate antenna weights. This class includes the popular Multiple

- Signal Classifier (MUSIC) algorithm (see R. O. Schmidt, "Multiple emitter location and signal parameter estimation," *IEEE Transactions on Antennas and Propagation*, vol. AP-34, pp. 276-280); Root-MUSIC (A. Barabell, "Improving the resolution of eigenstructured based direction finding algorithms," *Proc. ICASSP*, Boston, Massachusetts, 1983, pp. 336-339), and Estimation of Signal Parameters via Rotational Invariance Techniques (ESPRIT) (R. Roy and T. Kailath, "ESPRIT - Estimation of Signal Parameters via Rotational Invariance Techniques," *IEEE Transactions on Acoustics, Speech, and Signal Processing*, vol. ASSP-37, pp. 984-995, 1989). All of the above techniques are variations of a root class of maximum likelihood (ML) estimators with different requirements for antenna array spacing and calibration (see B. Otterstein *et al.*, "Analysis of Subspace Fitting and ML Techniques for Parameter Estimation from Sensor Array Data," *IEEE Transactions on Signal Processing*, vol. 40, no. 3, March 1992).
- Inaccuracies imposed by the measurement environment can limit AOA ML estimators (see P. Stoica and A. Nehorai, "MUSIC, Maximum Likelihood, and Cramer-Rao Bound," *IEEE Transactions on Acoustics, Speech, and Signal Processing*, vol. 37, no. 5, May 1989; B. Porat and B. Friedlander, "Analysis of the Asymptotic Relative Efficiency of the MUSIC Algorithm," *IEEE Transactions on Acoustics, Speech, and Signal Processing*, vol. 36, no. 4, April 1998; and M. Ghongho *et al.*, "Cramér-Rao Bounds and Maximum Likelihood Estimation for Random Amplitude Phase-Modulated Signals," *IEEE Transactions on Signal Processing*, vol. 47, no. 11, November 1999). Published and anecdotal evidence seems to indicate that ML methods such as MUSIC

experience difficulty in resolving sources even in fairly benign environments (see G. Tsoulos, *et al.*, "Wireless Personal Communications for the 21st Century: European Technological Advances in Adaptive Antennas," *IEEE Communications Magazine*, pp. 102-109, September 1997; A. L. Swindlehurst *et al.*, "Some Experiments with Array Data Collected in Actual Urban and Suburban Environments," published research paper, Royal Institute of Technology, Stockholm, Sweden).

Since the AOA estimate will ultimately drive the improvements any DABF will yield in CINR, other DABF technologies have sought to exploit signal characteristics other than angle-of-arrival. Constant modulus algorithms (CMA), for example, exploit the property in phase-modulated signals of a constant magnitude (or modulus) (see A. van der Veen, "An Analytical Constant Modulus Algorithm," *IEEE Transactions on Signal Processing*, vol. 44, no. 5, May 1996; and J. P. Kennedy *et al.*, "Adaptive antenna system and method for cellular and personal communication systems," U.S. Patent 5,771,439, June 23, 1998).

The second key feature of any DABF category is the optimization method employed to optimize the objective function. Most of the methods cited above employ what are known as signal-subspace or eigenstructure methods (see L. C. Godara, "Application of Antenna Arrays to Mobile Communications, Part II: Beam-Forming and Direction-of-Arrival Considerations," *Proceedings of the IEEE*, vol. 85, no. 8, August 1997). These methods generally estimate and perform some sort of decomposition of the covariance matrix of receiver signal and noise measurements (e.g., W. S. Youn and C. K. Un, "Eigenstructure method

for robust array processing,” *Electron. Lett.*, vol. 26, pp. 678-680, 1990; A. M. Haimovich and Y. Bar-Ness, “An eigenanalysis interference canceller,” *IEEE Transactions on Signal Processing*, vol. 39, pp. 76-84, 1991; B. Friedlander, “A signal subspace method for adaptive interference cancellation,” *IEEE Transactions on Acoustics, Speech, and Signal Processing*, vol. 36, pp. 1835-1845, 1988; and B. D. Van Veen, “Eigenstructure based partially adaptive array design,” *IEEE Transactions on Antennas and Propagation*, vol. 36, pp. 357-362, 1988).

The present invention builds on technology disclosed in a previous utility application filed on October 30, 2002 by G. Zancewicz, “System, Method, and Apparatus for Improving the Performance of Space Division Multiple Access and Other Systems that Shape Antenna Beams by Employing Postdetection Polarimetric Beamsteering and Utilizing Genetic Algorithms to Synthesize Beams,” United States Utility Patent Application (“Polarimetric Utility Application”). The present invention builds on such technology by specifying: (1) an objective function based on actual CINR measurements at the output of a demodulator; and (2) an optimization method based on a genetic algorithm. The present invention obtains CINR measurements by estimating the desired signal energy and the undesired interference+noise energy at the output of, for example, a CDMA matched filter. The use of genetic algorithms in antenna array processors has been disclosed previously in G. Zancewicz, “Application for United States Letters Patent for Genetic Adaptive Antenna Array Processor,” Attorney Docket 01049.0020U1, August 1, 2000.

OBJECT OF THE INVENTION

The present invention seeks to expand incremental capacity exploiting specific characteristics of wireless signals, for example, CDMA or OFDM signals, in order to define optimally suitable adaptive uplink and/or downlink antenna beams.

SUMMARY OF THE INVENTION

The present invention combines the processing for modulation/demodulation and digital adaptive beamforming in a single functional block. The DABF optimizes the antenna array element weights by using an objective function that measures the post-detection CINR output from the demodulator in the case of the uplink channel. In the preferred embodiment, the present invention combines processing for such beamforming with processing for CDMA modulation/demodulation or OFDM modulation/demodulation. In the preferred embodiment, the present invention employs genetic algorithms within the DABF process. In the preferred embodiment, the present invention matches the polarization of an antenna array with that of a mobile-of-interest by optimizing the polarization separately after optimizing antenna array weights.

To simplify discussion, the rest of the present application describes the present invention in the case of a CDMA Demodulator on the uplink channel. However, the present invention clearly applies to all types of modulation and demodulation techniques, including without limitation: Amplitude Modulation

(AM), Frequency Modulation (FM), and Quadrature Amplitude Modulation (QAM), as well as more complex modulation techniques such as CDMA (including without limitation: Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS)) and OFDM. The specific

5 functionality needed in the modulator/demodulator will depend on the specific modulation waveform and protocol employed. However, the present application clearly intends to apply the present invention to all such modulation/demodulation techniques. In addition, the present invention clearly applies to both demodulation on the uplink channel and modulation on the

10 downlink channel. In addition, the present invention can apply to utilization of the system, apparatus, and methods on both a base station or user equipment. In addition, the present invention can apply to both mobile and fixed wireless networks.

15

20

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of an apparatus that is a genetic adaptive array (GAA) system;

5 Figure 2 is a flow chart of a method for matching the polarization of the GAA system with that of a user;

Figure 3 is a diagram comparing a GAA system with a conventional system;

10 Figure 4 is a diagram showing a simulation model for a conventional system with angle of arrival (AOA) errors; and

Figure 5 is a Comparison of CINR of GAA v. CINR of Conventional System.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention includes the following system, apparatus, and method:

5

ξ A system comprising an antenna array with complex weights that are adapted by a Genetic Algorithm (GA) Optimizer. The system utilizes the actual CINR from the output of the CDMA Demodulator as the GA fitness metric (figure of merit).

10 ξ An apparatus combining the processing functionality of modulation/demodulation and digital adaptive beamforming in a single functional block.

ξ A method of matching the polarization of an antenna array with that of the mobile-of-interest by: (1) optimizing the polarization separately after the GA optimizes the antenna array weights; or (2) optimizing the polarization jointly with the GA optimizing the weights.

15

Structure of the Block Diagram

20 A GAA system comprises an antenna array with complex weights that are adapted by the GA Optimizer. The system utilizes the actual CINR from the output of the CDMA demodulator as the GA fitness metric (figure of merit).

Figure 1 shows a GAA system described by the present invention. The antenna array includes antenna elements 104 that transmit and/or receive signals

to and/or from the mobile-of-interest 100. Each antenna element i has a polarization vector, where ($i = 1$ through N), that is determined by the method described in Figure 2.

5 The system separates the antenna elements 104 by a distance 106. The distances between the antenna elements can be constant or can vary. For example, Table 3 in the Discussion section lists potential combinations of spacing or distances between antenna elements.

A GA Optimizer 108 generates and adaptively adjusts a complex weight 110 for each i -th antenna element 104.

10 A Component 112 sums the individual inputs from each antenna element 104 to produce a single complex-valued input sequence.

A CDMA Demodulator 114 accepts a single complex-valued input sequence and demodulates the digital input sequence to produce a real-valued digital output sequence. The real-valued digital output produced by the CDMA
15 Demodulator 114 corresponds to an estimate of some figure of merit of the digital input sequence, including without limitation: carrier-to-noise ratio (CNR), carrier-to-interference ratio (CIR), carrier-to-interference-and-noise ratio (CINR), bit error rate (BER), frame error rate (FER), packet error rate (PER), or energy-per-bit-to-noise (E_b/N_o) ratio. In the preferred embodiment, the present
20 invention utilizes the actual CINR as the figure of merit.

Functional Relationships in Block Diagram

In the uplink channel, the antenna array comprising antenna elements 104 receives input signals from the mobile-of-interest 100 and interfering mobiles 102.

The antenna array transmits output to the Component 112.

5 The Component 112 sums the individual signals from each antenna element 104 to produce a single complex-valued input sequence and transmits such sequence to the CDMA Demodulator 114.

The CDMA Demodulator 114 demodulates the digital input sequence to produce a real-valued digital output sequence. In the preferred embodiment, the
10 sequence corresponds to the actual CINR. The CDMA Demodulator 114 transmits the sequence to the GA Optimizer 108.

The GA Optimizer 108 adaptively adjusts the complex array weights in order to maximize the CINR in accordance with the genetic algorithm implemented.

15

Discussion

The present application presents information on the set of simulation experiments that were performed to evaluate the performance of the GAA
20 system. The GAA system comprises an antenna array that uses a genetic algorithm (GA) to adjust adaptively the complex weights of the array to maximize the CINR. Prior utility applications by the present inventor cited in the “Background” section discuss the use of genetic algorithms in the present application.

The simulation scenario includes a single mobile-of interest 100 with many multiple interfering mobiles 102 at random positions. The present invention used a different set of interferer positions for each experimental trial.

The GA Optimizer 108 parameters relate to the internal structure of the GA and include parameters such as Number of Generations, Probability of Crossover, Probability of Mutation, etc. The array topology relates to the spatial configuration of the array and includes parameters such as the number of elements and the element spacing. The polarization optimization comprised performing a “search” for the best polarization after the GA Optimizer 108 optimized the array weights.

The present application compares the present invention to conventional systems by simulating estimation errors inherent in AOA estimation algorithms and comparing the performance to the GAA system.

The following sections discuss each major issue covered by the present application.

Array Output

The following equation describes the output of the array for the general case:

$$V_{\text{out}} = \sum_{m \text{ sources}} \sum_{n \text{ elements}} w_n^* \exp(-jk_0 |\mathbf{r}_m - \mathbf{r}_n|) \frac{\langle \mathbf{p}_n, \mathbf{p}_m \rangle}{|\mathbf{r}_m - \mathbf{r}_n|}$$

where \mathbf{r}_m and \mathbf{r}_n are the position vectors of the sources and the array elements, respectively and $\langle \mathbf{p}_n, \mathbf{p}_m \rangle$ denotes the inner product of the polarization vectors of the n-th elements with the m-th source. With the assumption of perfect power
 5 control, the $1/r$ factor vanishes. The present invention assigns an identical polarization state to each element, denoted by $\mathbf{p}_{\text{array}}$. Given these assumptions, the array output reduces to the following:

$$V_{\text{out}} = \sum_{\text{m sources}} \langle \mathbf{p}_m, \mathbf{p}_{\text{array}} \rangle \sum_{\text{n elements}} w_n^* \exp(-jk_0 |\mathbf{r}_m - \mathbf{r}_n|)$$

10

The CINR is the ratio of the output due to the mobile-of-interest 100 to the output due to interfering mobiles 102 and the background noise floor:

$$\text{CINR} = \frac{\left| \sum_{\text{n elements}} \langle \mathbf{p}_{\text{mobile}}, \mathbf{p}_{\text{array}} \rangle w_n^* \exp(-jk_0 |\mathbf{r}_{\text{mobile}} - \mathbf{r}_n|) \right|^2}{\sum_i \left| \sum_{\text{n elements}} \langle \mathbf{p}_i, \mathbf{p}_{\text{array}} \rangle w_n^* \exp(-jk_0 |\mathbf{r}_i - \mathbf{r}_n|) \right|^2 + \sigma_{\text{noise}}^2}$$

15

20

$$\text{CINR(dB)} = 10 \log_{10}(\text{CINR})$$

The simulation runs used random positions for the interfering mobiles 102. The simulation positioned the mobile-of-interest 100 at a range of 2000m

and angle of 80 degrees. The simulation typically assumed the number of interfering mobiles 102 to be 100 and the number of trials (position configurations of all sources) to be 100.

5

Range of Mobile	Angle of Mobile	Number of Interferers	Number of Trials
2000 m	80 degrees	100	100

Table 1: Default Simulation Parameters

GA Optimizer

10

The GA Optimizer 108 is the engine that adaptively adjusts the complex array weights in order to maximize the CINR. The associated parameters include the following:

- ξ Number of generations
- 15 ξ Number of chromosomes in population
- ξ Probability of crossover
- ξ Probability of mutation

The present application determined the values of these parameters empirically and shows them in the table below:

20

Generations	Chromosomes	Crossover Probability	Mutation Probability
100	20	0.5	0.03

Table 2: GA Optimizer Simulation Parameters

The present invention selects the values for the number of generations and
5 number of chromosomes based on computational feasibility. In general,
increasing the number of generations and number of chromosomes should result
in better or equal performance. As the computational power of semiconductors
improves, the present invention can increase the number of generations and
number of chromosomes processed in the GA Optimizer 108.

10

Array Topology

The array topology is related to the spatial configuration of the array and
includes parameters such as the number of elements 104 and the element spacing
15 106. The present application considers many different topologies. The present
application summarizes the results in the table below:

20

Array Topology	Active Elements	Worst CINR	Best CINR	Average CINR	Standard Deviation	Median	99 th ($X \geq x$)	90 th ($X \geq x$)
U8C	8	1.57	53.32	22.45	11.30	20.83	2.35	9.07
U8S	8	0.15	51.49	22.29	9.75	23.14	0.92	10.16
OGR-8	8	-1.87	45.52	20.24	9.98	18.58	-1.16	9.26
U4C+p	8	-0.01	43.52	17.25	10.95	16.11	0.64	3.69
U6C+p	12	-2.92	49.23	21.80	11.03	21.02	-2.14	7.25
U8C+p	16	3.85	53.32	23.90	11.44	22.14	4.60	11.03
U8S+p	16	0.93	51.49	24.09	10.27	24.51	1.68	11.29
OGR8+p	16	-1.65	45.52	22.35	10.67	19.50	-0.94	9.90
U16C	16	1.33	47.15	23.39	9.73	24.51	1.79	8.89
U16+p	32	1.94	58.30	25.35	10.57	25.48	2.79	9.83
U35	35	2.84	52.47	26.13	10.21	25.12	3.58	14.00
U35+p	70	2.93	64.64	29.04	10.45	27.33	3.86	16.82

Table 3: CINR for Different Array Topologies

Polarization Optimization

5

The present application examines the performance gain from matching the polarization of the array to the mobile-of-interest. In one embodiment, the present invention matches polarization by optimizing the polarization jointly with the GA optimizing the antenna array weights. In the preferred embodiment, the present invention matches polarization by optimizing the polarization separately

10

with an “exhaustive” search after the GA optimizes the antenna array weights. In the preferred embodiment, the GA optimization loop runs over many iterations (generations) and converges to an optimal set of weights using circular polarization. At this point, the present invention considers the weights fixed and

5 the polarization search then attempts to improve the CINR by trying different array polarization angles from the set $\{0, 45, 90, 135, 180, -135, -90, -45\}$. The present invention can include different sets of polarization angles, including without limitation: sets with different angles, sets with smaller or larger spaces between angles, and sets of angles that vary continuously, instead of discretely.

10 Simulations show that the preferred embodiment yields higher performance. Figure 2 is a flow chart listing the steps in the method.

Detailed Steps for Executing Method

15 At Step 202, the Antenna Array 200 generates an array output.

At Step 206, the CDMA Demodulator 204 generates a real-valued digital output sequence. The real-valued digital output produced by the CDMA Demodulator 204 corresponds to an estimate of some figure of merit of the digital input sequence, including without limitation: carrier-to-noise ratio (CNR),

20 carrier-to-interference ratio (CIR), carrier-to-interference-and-noise ratio (CINR), bit error rate (BER), frame error rate (FER), packet error rate (PER), or energy-per-bit-to-noise (E_b/N_o) ratio. In the preferred embodiment, this figure of merit is the actual CINR.

At Step 210, the GA Optimizer 208 adaptively adjusts the complex array weights in order to maximize the CINR. The optimal set of weights is w_{opt} 210.

At Step 212, the GA optimization loop determines whether the iteration is the last one generated in accordance with any criteria set by the GA Optimizer 208. If no 214, the method returns to Step 202 until it converges to an optimal set of weights. If yes 216, the method considers the antenna array weights fixed and then proceeds to conduct a search for the optimal polarization.

At Step 218, the Polarization Optimizer searches for the optimal polarization by trying different array polarization angles from any set of polarization angles. In one embodiment, the set of polarization angles can include $\{0, 45, 90, 135, 180, -135, -90, -45\}$.

At Step 220, the Polarization Optimizer determines the optimal polarization and then adaptively adjusts the polarization vectors for each i -th antenna element.

15

Comparison to Conventional Systems

In order to compare the GAA system with a conventional system, the present application makes several assumptions in order to characterize the conventional system. The main assumption is that any conventional system will utilize some type of AOA (angle of arrival) algorithm that estimates the source directions and feeds this information into the DABF (digital adaptive beam former) optimization algorithm to update the complex weights of the array. The present application presents simulations that suggest that the CINR is very

sensitive to AOA errors, especially as the number of interfering mobiles increases. The GAA system instead looks directly at the output of the CDMA demodulator and feeds the CINR into the GA optimizer that adapts the complex array weights. Figure 3 compares these two systems.

5

Simulation Model for Conventional System with AOA errors

Several algorithms exist for AOA estimation including MUSIC and ESPRIT. In one approach, the present application implements MUSIC. In
10 another approach, the present application implements the Cramer-Rao bound in the interest of applying the simulation to a general model. The Cramer-Rao bound represents the lower bound for any maximum-likelihood estimate and therefore applies regardless of the specific AOA estimation algorithm used.

To simulate a conventional system with AOA estimation errors, the
15 present application applies random angle errors to the position vectors of the mobile-of-interest and interferer mobiles. The present application sets the variance of the angle errors to be the Cramer-Rao bound variance. Therefore, this noise is inherent in any conventional system that uses AOA estimation information for the purposes of array weight optimization. The present
20 application uses noisy positions (positions with random errors added) as inputs to the Optimizer that determine the optimal weights. Once the Optimizer determines the weights, the CINR is evaluated at the *true* positions. This mismatch effectively simulates the performance degradation due to AOA estimation errors. Figure 4 shows the simulation model.

The present application compares the conventional system with AOA errors and the preferred embodiment of the present invention by evaluating the performance as the Number of Interferers and the variance of the angle error in position varies. The present application summarizes the simulation results in the

5 following table and graph.

(angle error) degrees	Number of Interferers	Pre-detect SNR (dB)	CINR—GAA (dB)	CINR—Conventional (dB)
0.08	15	20	30.5	9.6
0.08	20	20	29.0	7.2
0.08	50	20	23.9	2.5
4.65	100	15	22.4	-16.5
2.58	75	15	22.6	-14.3
0.14	50	15	28.1	-4.9
0.14	20	15	29.0	0.3
0.14	15	15	30.5	1.9
0.04	50	25	23.95	13.4
0.04	20	25	29.0	18.5
0.04	15	25	30.5	19.6
0.08	2		41.0	36.3

Table 4: Comparison of CINR of GAA with CINR of Conventional System

As Table 4 and Figure 5 show, the preferred embodiment of the present invention generates significantly higher CINR than a conventional system. The preferred embodiment improves its relative performance as the number of mobile interferers increases. The preferred embodiment improves its relative performance as the AOA errors increase. In wireless networks that operate in environments with many reflecting surfaces, e.g., wireless local area networks in indoor environments, the potential for AOA errors can increase. Thus, the preferred embodiment could generate particularly higher performance than a conventional system could in such networks.

While the utility application describes the present invention in detail with particular reference to preferred embodiments, sequence of steps, and number of steps, other embodiments, step sequences, and a larger or smaller number of steps can achieve the same results. Variations and modifications of the present invention will be obvious to those skilled in the art. The inventor intends to cover in the claims of the present application all such variations, modifications, and equivalents.

1 What is claimed is:

2 1. A system for increasing the capacity of wireless systems employing
3 SDMA receivers and other systems that shape antenna beams by combining
4 the processing for demodulation and digital adaptive beamforming in a single
5 functional block, comprising:

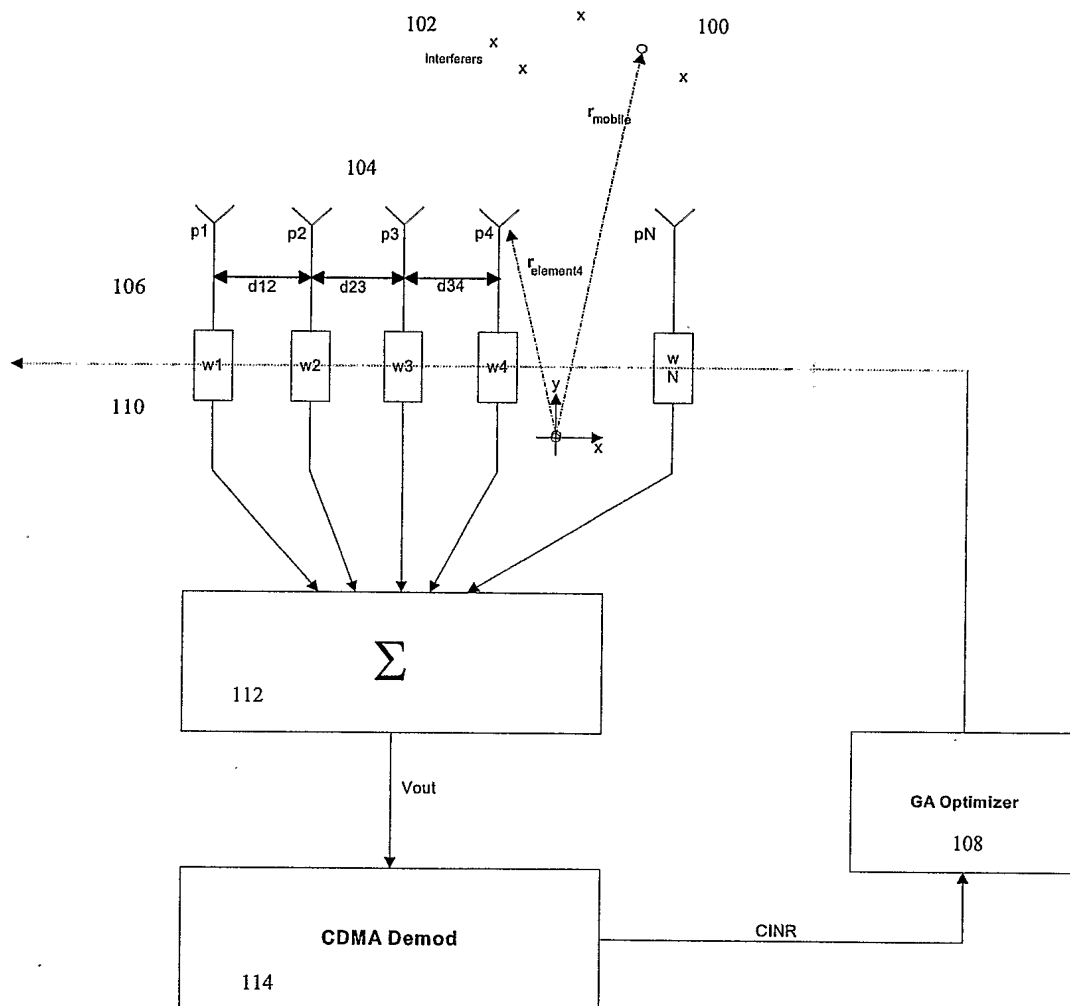
6 an antenna array;

7 a genetic algorithm (GA) Optimizer that adaptively adjusts the
8 complex weights for each antenna element;

9 a component that sums the individual signals from each antenna
10 element to produce a single complex-valued input sequence; and

11 a demodulator that accepts a single complex-valued input
12 sequence and demodulates the digital input sequence to produce a real-
13 valued digital output sequence. The real-valued digital output produced
14 by the demodulator corresponds to an estimate of some figure of merit of
15 the digital input sequence, including without limitation: carrier-to-noise
16 ratio (CNR), carrier-to-interference ratio (CIR), carrier-to-interference-
17 and-noise ratio (CINR), bit error rate (BER), frame error rate (FER),
18 packet error rate (PER), or energy-per-bit-to-noise (E_b/N_o) ratio. In the
19 preferred embodiment, this figure of merit is the actual CINR. In the
20 preferred embodiments, the demodulator is a CDMA demodulator or
21 OFDM demodulator.

Figure 1: GAA System



w_i = complex weight for the i -th element
 p_i = polarization vector for the i -th element
 d_{ij} = distance between the i -th and j -th element
 O = mobile of interest
 x = interfering mobile

Figure 2: Polarization Search in the Context of the Overall System

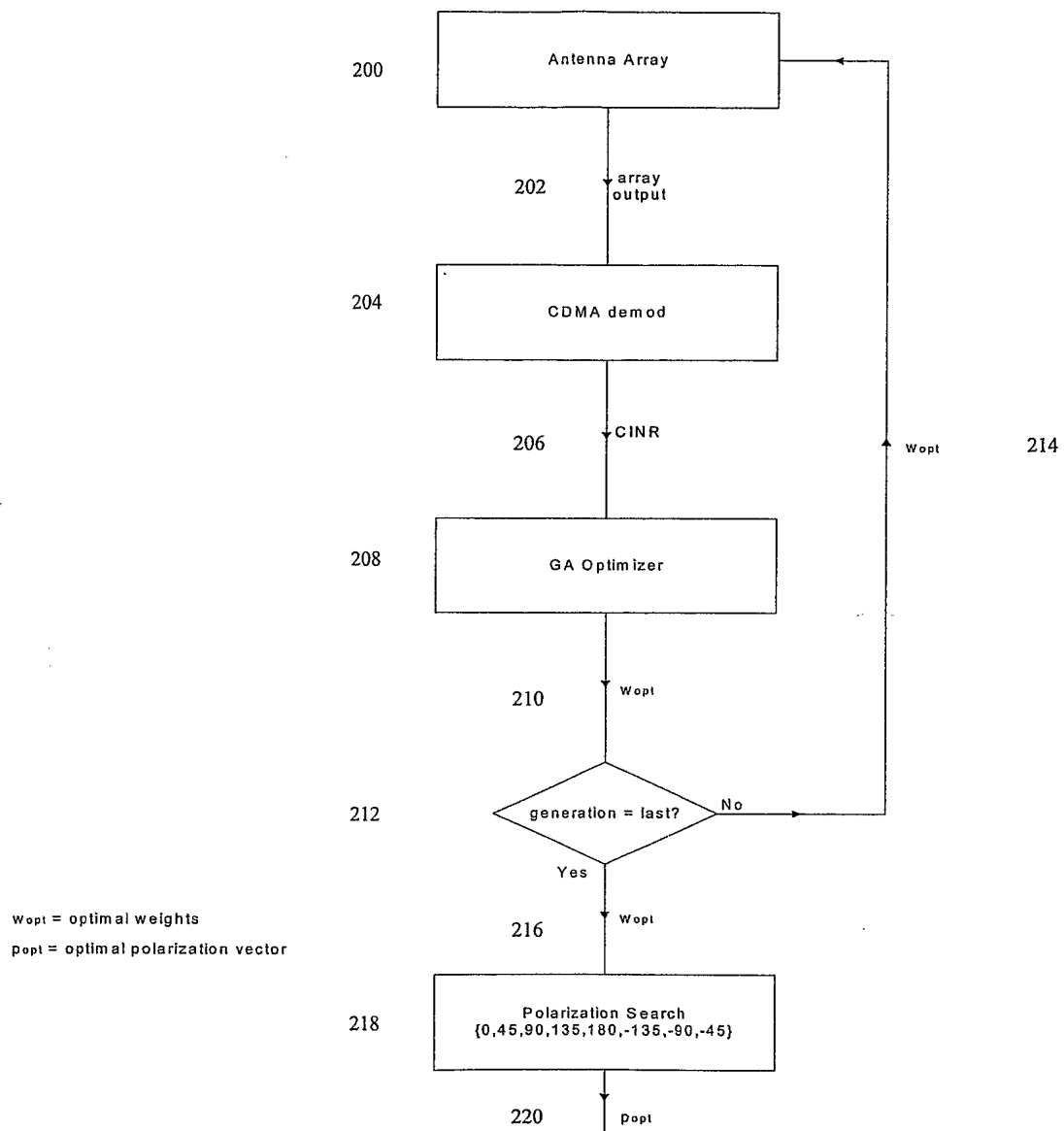


Figure 3: GAA vs. Conventional System

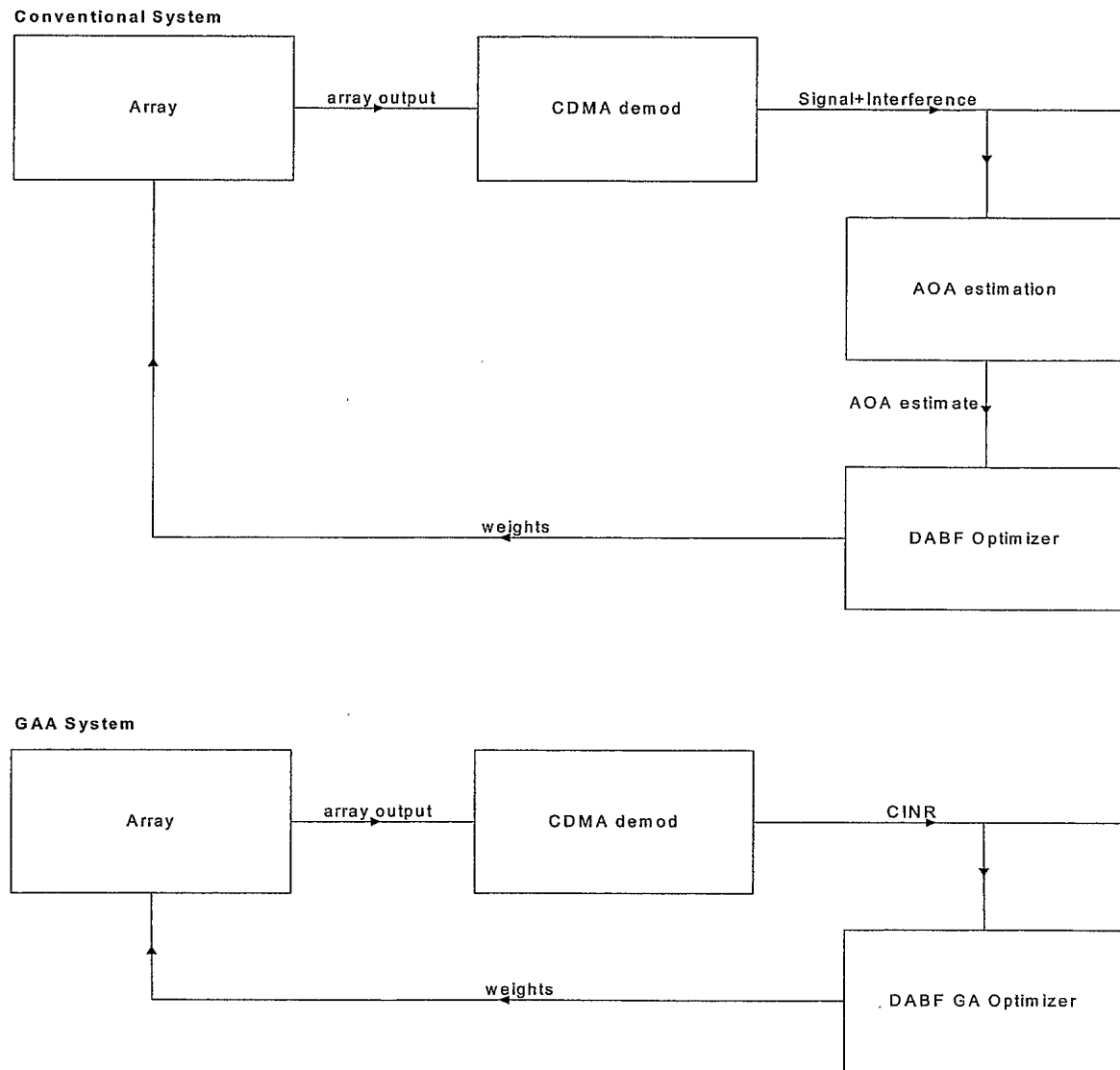
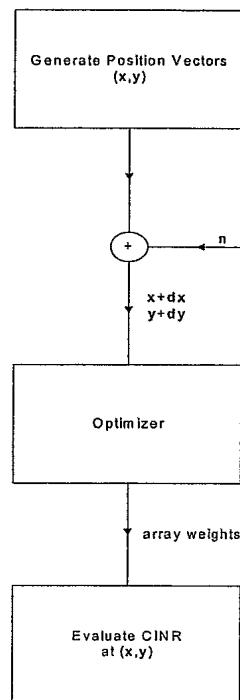
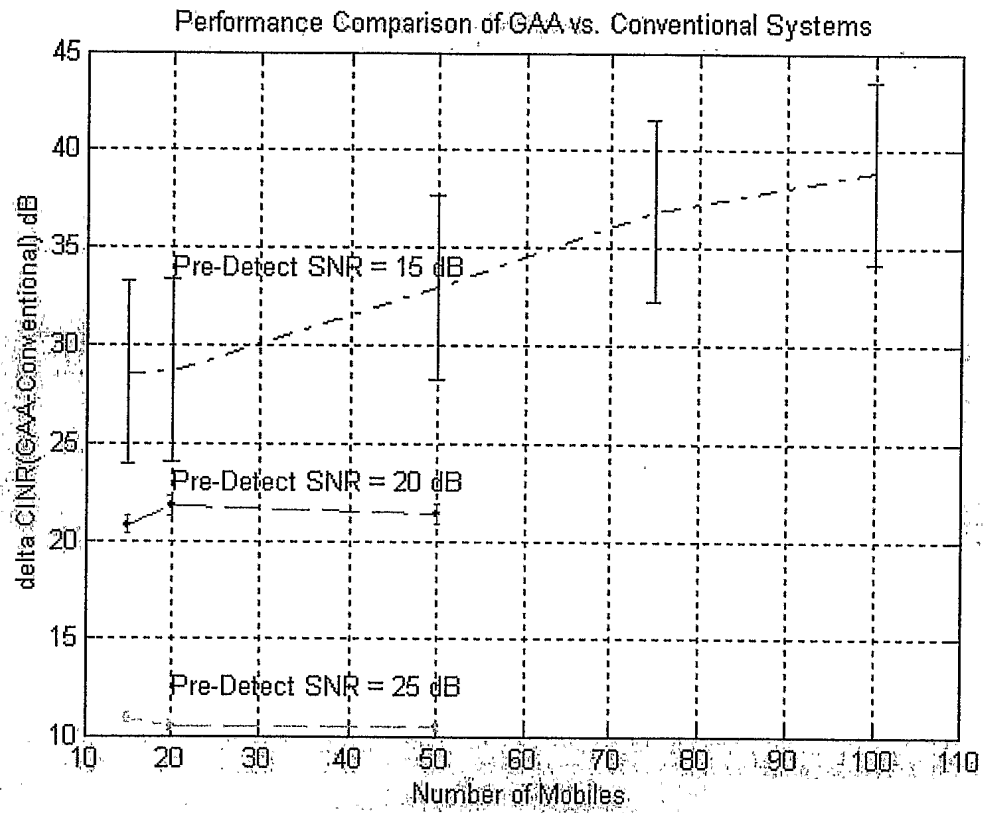


Figure 4: Simulation model for conventional system with AOA errors

x = vector of x-coordinates of interfering mobiles
 y = vector of y-coordinates of interfering mobiles
 n = noise added to positions

Figure 5



Comparison of CINR of GAA v. CINR of Conventional System